

Vacuum Insulator Flashover



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High-performance pulsed-power systems are used in numerous applications related to national security. The vacuum insulator is a critical component of such systems, often limiting peak performance. If designed incorrectly the insulator can be the weak link leading to failure of the entire system. Scientific knowledge developed from simple experiments provides understanding of

important physics involved in insulator performance, but is not readily translated into a reliable tool for predicting operational performance. We are developing a computer model of electrical breakdown at the dielectric/vacuum interface. We are leveraging LLNL's advances in computational resources to bridge the gap between knowledge and application.

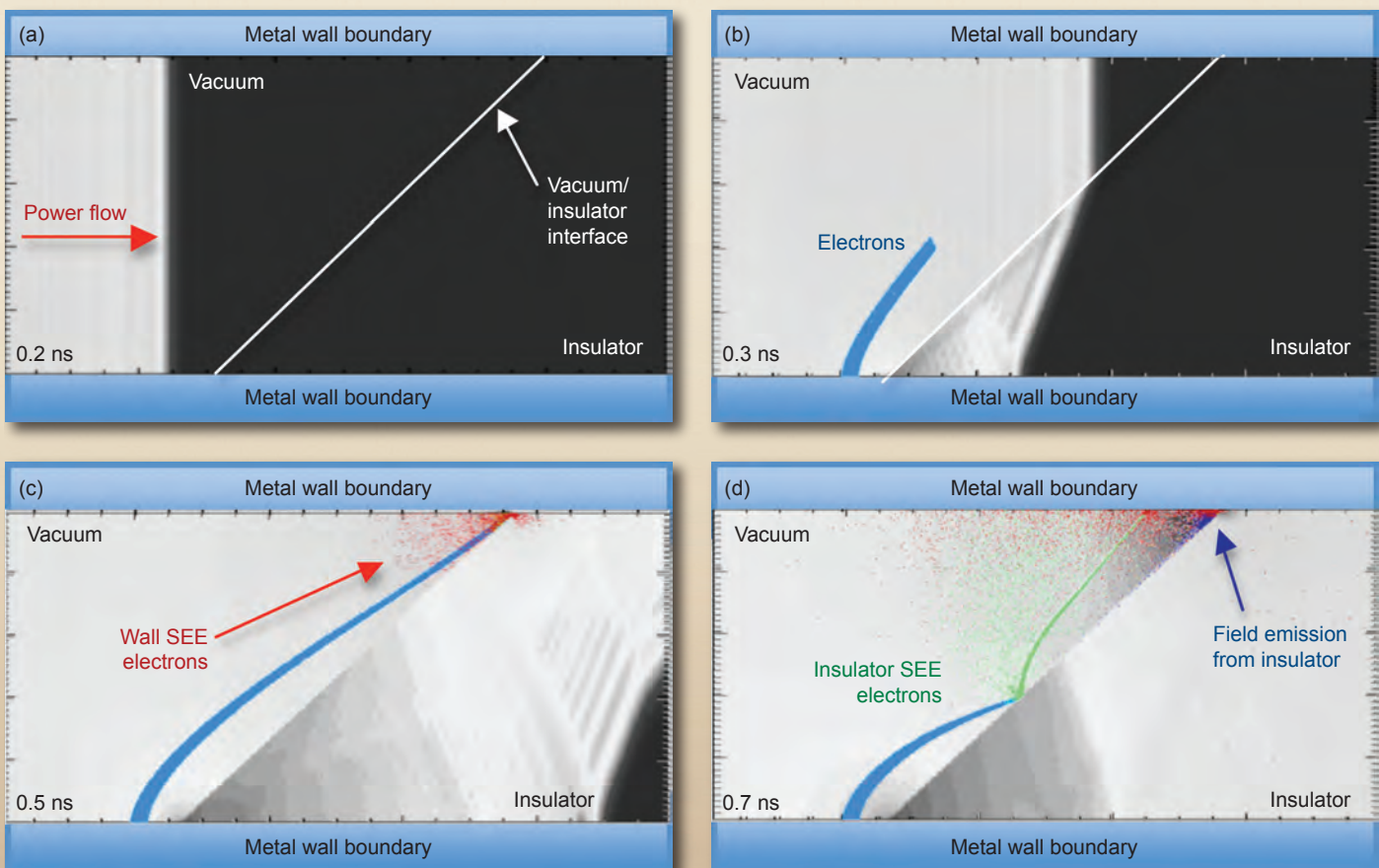


Figure 1. Power flow channel simulated with VORPAL. (a) Electromagnetic power flows from the left passing through a 45° angled insulator. The grey scale background indicates the relative strength of the electric field (white is high; black is zero). (b) Shortly before 0.3 ns simulation time, electrons (light blue) are emitted from a small area of the wall as a hypothesized perturbation. (c) These electrons cross the vacuum and are swept across the opposing wall producing secondary electrons (red). (d) At later times the emitted electrons strike the insulator, producing additional secondary electrons (green) and charging the insulator. This charging attracts the emitted electrons. Also, high fields near the upper face of the insulator cause field emission from the insulator (blue).

Project Goals

We wish to produce a computational methodology for designing high-voltage vacuum insulators for pulsed-power devices. We expect to demonstrate that a few basic physics phenomena are responsible for the initiation of electrical breakdown across the dielectric/vacuum interface, known as vacuum insulator flashover. Varying the geometry, materials, and environment used in simulations will show how different initiation mechanisms evolve. This tool will make it possible to study complex insulator designs in realistic operational applications and to predict performance. We will also deliver a proposed insulator design for the next generation of magnetic flux-compression generators.

Relevance to LLNL Mission

This project directly supports the Energy Manipulation pillar of the Science, Technology, and Engineering foundation. Our computational model enhances LLNL's status as a world-class center for high-voltage vacuum insulator design, development, and testing. Improved vacuum insulators will have immediate impact on explosively driven flux compressors and compact accelerator designs.

FY2009 Accomplishments and Results

A commercial 3-D, fully electromagnetic Particle-in-Cell (PIC) Code, VORPAL, was acquired and installed on an LLNL

Linux cluster. We modified the source code of the Secondary Electron Emission (SEE) model for our application. This phenomenon produces electrons from a surface due to impact by incident electrons. If more electrons emerge from the surface than impact, an avalanche of electrons can be formed. For the materials of interest, this avalanche is considered one of the principle mechanisms of flashover.

A power flow channel simulated with VORPAL is shown in Fig. 1. The power enters from the left and passes through the insulator. Field emission from a small area of the metal wall boundary introduces electrons into the simulation. The magnetic field associated with the electromagnetic pulse bends the orbits of electrons, leading to impacts with the insulator. SEE occurs both on the insulator and on the metal wall. This simulation emphasizes several issues of flashover. The most important is the effect of SEE in generating an electron avalanche.

Next is the effect of the self-consistent magnetic field on the orbits of the electrons. For a electromagnetic power flow, both electric and magnetic fields will be present. Past design of insulators has often been accomplished with electrostatic modeling, neglecting the magnetic field. In low power flow systems this is a legitimate technique, but for high power systems important phenomena such as self-magnetic insulation will be overlooked.

Finally, although not apparent in the figure, the total current across the insulator is not sufficient to cause a complete voltage collapse. The final stage of flashover must involve plasma production in a desorbed gas layer on the insulator surface. Such a layer has been experimentally observed. Neutral gas ionization studies (Fig. 2) have started by simulating the propagation of an electron beam through argon and the resulting collisional ionization.

Related References

1. Perkins, M. P., T. L. Houck, J. B. Javedani, G. E. Vogtlin, and D. A. Goerz, "Progress on Simulating the Initiation of Vacuum Insulator Flashover," *Proc. 17th IEEE International Pulsed Power Conference*, 2009.
2. Nieter, C., and J. R. Cary, "VORPAL: a Versatile Plasma Simulation Code," *J. Comp. Phys.*, **196**, pp. 448–472, 2004.

FY2010 Proposed Work

The effect of electron interactions with a desorbed neutral gas will be the major focus area in the coming year. Water has been identified as a leading contaminate in vacuum systems. A self-consistent gas desorption model will be incorporated into the code. A desired goal is to determine an improved insulator through simulations and design a laboratory experiment to validate our results.

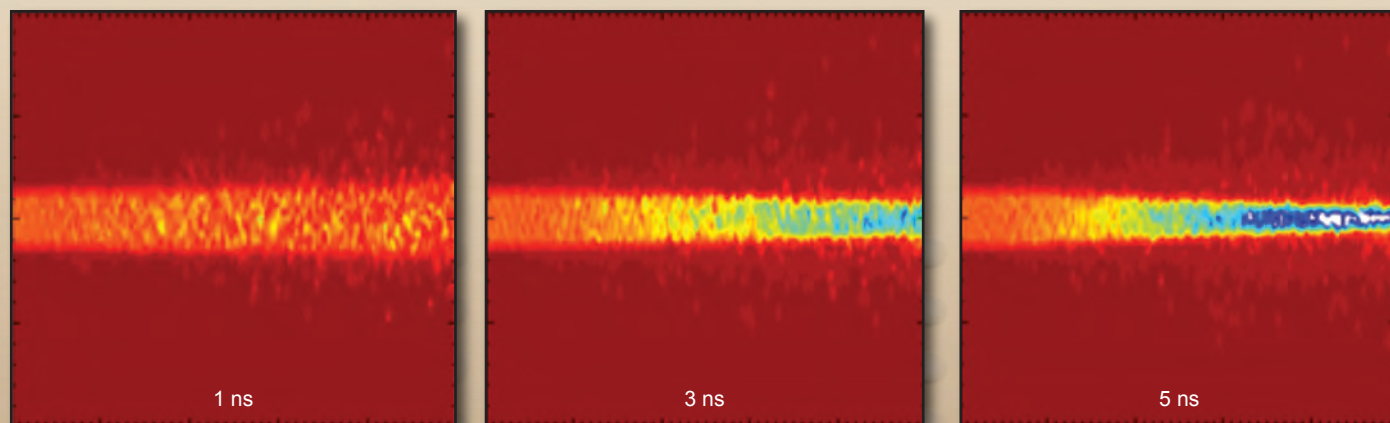


Figure 2. Simulation showing the effect of an energetic electron beam entering a volume of argon, ionizing the gas from the left. The color scale shows the current density with white high, red low. As time elapses the argon ions in the beam path focus the beam into a high density channel.